EXPERIMENTS TO STUDY THE EFFECT OF DISSIPATION BLOCKS UPON ENERGY OF FLOW DOWNSTREAM THE COMPOUND WEIRS

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ABSTRACT

The objective of this study was to investigate the hydraulic characteristics such as energy dissipation, reduction of hydraulic jump and roller length on unconventional types of blocks using the experimental works. Values of the relative energy dissipation ratio ($E_2/E_1$), relative length of hydraulic jump ($L_j/Y_2$), and relative roller length ($L_r/\Delta Y$) for different blocks in this study were found in terms of the primary Froude numbers. Results indicated that the compound weir with ($60^\circ, 90^\circ$) lower V-notch with all dissipation blocks have a high efficiency especially at the high discharges. Also, the hydraulic characteristics values of applied discharges on the surface of the triangular cut angles with ($45^\circ, 60^\circ$) were better than other configuration of blocks.

Key words: Dissipation, Blocks, Energy, Compound, Weirs

1. INTRODUCTION

The specific energy of the flow always decreases during the flow. So the specific energy at any discharge ratio of the flow either decreases or increases. The specific energy of the discharge ratio is depends on the flow depth (Giglou et al., 2013). In the small low-head hydraulic structures, the Froude Number of discharge flow is typically not more than 4.5, which means it is a low Froude Number flow. Bottom-flow energy dissipator is usually adapted to low-head hydraulic structure, by means of engineering measures, the hydraulic jump is controlled to the stilling basin, and energy is dissipated by the Surface vortex roll and a strong vortex turbulence of hydraulic jump. To improve energy dissipation rate, decrease the length and height of stilling basin, the dissipation blocks are applied on the apron to form a forced hydraulic jump. Usually, when the energy is dissipated by hydraulic jump, a serious fluctuating pressure was generated on the stilling basin apron,
and the fluctuating uplift force will sometimes make the apron unstable. The fluctuating pressure of hydraulic jump with low Froude Number is very complex \cite{Zhou2011}.

Abdel-Aal et al., \cite{2003} studied and developed theoretical models for the hydraulic jump as an important method for energy dissipation to predict the depth ratios of the radial hydraulic jumps at negative steps downstream of the control structures when the stilling basins was ended with a sill. An experimental program was conducted to enable verification of the developed theoretical models. Good agreement between theoretical and experimental results was obtained. The developed models were recommended for use in the design of radial stilling basin to compute the depth ratios which was needed to complete the dimensioning of the stilling basin.

Irzooki et al., \cite{2005} presented a laboratory experiments to study the hydraulic performance of stilling basin with unusual shapes of baffle blocks. Seven groups of baffle blocks were selected, three of these groups were cut with angle (15º, 30º, 45º) horizontally, another three groups were cut with the same above angles, but vertically, and the seventh group was cut with semi-cylindrical section. They concluded that the cutting baffle blocks were generally better than the standard blocks in dissipation of a hydraulic energy and reduction of a hydraulic jump length, but a ratio of drag force applied on cutting baffle blocks was greater than this ratio on the standard blocks for the same flow conditions and angle of cut. The cutting baffle blocks gives a greater value of the energy dissipation which was (80.62%) than the standard blocks and greater value of reduction in the hydraulic jump length which was(37.5%),also these blocks gives maximum increase of the drag force ratio which was (97%) greater than its value on the standard baffle block.

Omer et al., \cite{2008} presented study to indicate the drag coefficient, pressure distribution and flow types on unconventional types of angularly cut baffle blocks and compared the results with standard baffle blocks by using the Fluent program and the experimental results. They concluded that values of the drag coefficient for the vertically cut blocks were less than the horizontally cut baffle blocks in the same flow conditions. Also, maximum values of applied pressures on the surface of the vertically cut baffle blocks were less than on other models which makes them more better than others.

Abbas, \cite{2009} investigated an experimentally the hydraulic performance of the compound hydraulic jump and plunge pool stilling basin operating under high head for Makhool Dam, two series of tests were carried out; the first series are on the model as it was designed, while the second series were on a modified model by adding two rows of chute blocks. The results indicated that for the first model the stilling basin length can be reduced and there was negative pressure at the beginning of the jump on the sloping apron with high turbulence and unstable water surface. After adding the chute blocks, the tests of the second model indicated that the stilling basin length can be reduced and all pressures were positive with reasonably stable water surface as well as lower turbulence. Therefore, chute blocks were recommended to be added.

Retsinis et al., \cite{2011} introduced the local change of mechanical energy within inclined channels in sluice gate and weir flows based on experimental measurements. The dimensionless local mechanical energy changes, in general loss for sluice gate flows and gain for weir flows were associated to the dimensionless geometrical characteristics and angle of longitudinal slope of channel.

Kurukji, \cite{2012} presented an experiments to study energy dissipation for stepped spillway in addition to the elimination of air pockets which take place at steps by using obstructions along the edge of steps. The results of the experiments showed that the obstructions were very successful in eliminating air pockets and had a positive effect on energy dissipation along the stepped spillway, the results also indicated that the use of these obstructions should be started from second step until the middle step of the spillway.

Maatooq et al., \cite{2013} analyzed the Diyala weir problems and compares it with the safe limit and proposes the treatment for these problems. It was concluded that the scour occurs due to the position of the hydraulic jump and the sequence depth of the jump was higher than the tail
water depth. Some treatment procedures were suggested, these treatments cover this problem by presenting a suitable stilling basin as well as recommended to use a low weir at end of basin to produce a back water curve that should be increased the stage of tail water and ensuring the stability of a hydraulic jump.

2. EXPERIMENTAL APPROACH

Experiments were carried out in the hydraulic laboratory of the civil engineering department, college of engineering, university of Babylon. This experimental work was performed in a horizontal rectangular open channel with dimensions of approximately 10 m long with an adjustable slope, 0.45 m deep and 0.3 m wide (as shown in figure 1). The channel consisted of toughened glass walls to enable visual observation of 10mm thick, and a stainless steel floor. Two movable carriages with point gauges with accuracy of (0.5mm) were mounted on brass rails at the top of channel sides to measure the heads over weir and downstream the hydraulic jump. Water was supplied from a sump tank by a centrifugal pump with a maximum capacity 40 l/sec., raising water by pump from the storage tank to the flume then returns to ground tank by vertical outlet at the end of the flume. Water discharge was measured by using flow meter. Flume bed was maintained at a horizontal slope during all of the testing.

![Hydraulic flume used in present work](image)

**Figure (1):** Hydraulic flume used in present work

Six sets of experiments were performed for a total of 240 runs. The first set consisting of 30 runs was performed using a triangular cut blocks of (θ=45°) to simulate a classical hydraulic jump in stilling basin with baffle blocks and end sills. Further runs consisting of (25 runs) for the rest groups of dissipation blocks (5 runs for each) for a particular type of compound weir. According to hydraulic flume operation mode and stage discharge relation for compound weirs, the model test conditions were selected, and the Parameters of experiment conditions showed in table (1). Figures (2) show the main details of the compound weir models.
Table (1): Important characteristics of compound weir models used in this study

<table>
<thead>
<tr>
<th>Compound Weir Model</th>
<th>Model No.</th>
<th>Dimensions (cm)</th>
<th>Weir Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular + Half Circle Notch</td>
<td>1</td>
<td>Height 25</td>
<td>Width 20</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Height 25</td>
<td>Width 10</td>
</tr>
<tr>
<td>Rectangular + Triangular Notch</td>
<td>3</td>
<td>Height 25</td>
<td>Width 20</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Height 25</td>
<td>Width 11.65</td>
</tr>
<tr>
<td>Rectangular + Trapezoidal Notch</td>
<td>5</td>
<td>Height 25</td>
<td>Width 5.0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Height 25</td>
<td>Width 5.0</td>
</tr>
<tr>
<td>Stepped Notch</td>
<td>7</td>
<td>Height 25</td>
<td>Width 10</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Height 25</td>
<td>Width 5</td>
</tr>
</tbody>
</table>

The main dimensions and specifications of the energy dissipation blocks were presented in table (2). Figure (3) shows the top view for basins used in this study.

Figure (2): Definition sketch showing dimensions and specifications of compound weir models (all dimensions are in cm)
Table (2): Dimensions and specifications of the energy dissipation blocks used in the study

<table>
<thead>
<tr>
<th>Type of Cutting Angle</th>
<th>Block Numbers</th>
<th>Dimensions Width (cm)</th>
<th>Length (cm)</th>
<th>Height (cm)</th>
<th>Angle of Cutting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangular</td>
<td>8</td>
<td>5.0</td>
<td>8.0</td>
<td>3.0</td>
<td>45°</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5.0</td>
<td>8.0</td>
<td>3.0</td>
<td>60°</td>
</tr>
<tr>
<td>Horizontal</td>
<td>8</td>
<td>5.0</td>
<td>8.0</td>
<td>3.0</td>
<td>60°</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5.0</td>
<td>8.0</td>
<td>3.0</td>
<td>110°</td>
</tr>
<tr>
<td>Vertical</td>
<td>8</td>
<td>5.0</td>
<td>8.0</td>
<td>3.0</td>
<td>60°</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5.0</td>
<td>8.0</td>
<td>3.0</td>
<td>110°</td>
</tr>
</tbody>
</table>

In order to evaluate the efficiency of the stilling basin with new types of dissipation blocks, the experiments were conducted and the necessary measurements for each type of weir notches were collected. Followed by analyzing the results and then compare it with other weir models to find out the models most suitable for applicable combination which represent in this research energy dissipation ratio and hydraulic jump length ratio for each specific weir.

(A): Triangular cutting angle for dissipation blocks (45°, 60°)

(B): Horizontal cutting angle for dissipation blocks (60°, 110°)
The general method adopted for sequencing all experiments, was performed by repeats the same steps in each experiment by installing the dissipation blocks on a glass plate and organizes a certain distance between the blocks based on the recommendations of the U.S. Bureau of Reclamation USBR (Water Measurement Manual, 2001) to simulate stilling basin, and then install them on the floor of the channel at a distance from the nape of compound weir. Thereafter passing a certain discharge, measurements were taken and new discharge was released, and so on; the following measurements were taken for all tests conducted on different groups of dispassion blocks:

1- Measuring the discharge passing in the channel.
2- Measure the water level over compound weir notch (Y₁) by using point gage.
3- Measure the depth of flow after hydraulic jump directly.
4- Measure the average depth of flow after the end of the hydraulic jump directly (Y₂).
5- Measure the length of the hydraulic jump (Lₗ).
6- Measure the length of the hydraulic jump roller (Lᵣ).

Then the following calculations were performed:
1- Calculate the initial velocity of flow (v₁) through weir notch and subsequent velocity (v₂) via continuity equation:

\[ v = \frac{Q}{A_t} \]  

..... [1]

In which;
\( v \) = velocity of flow (L/T).
\( Q \) = discharge (L³/T).
\( A_t \) = area of water way (L²).
2- Calculate the primary Froude Number (Fr₁), and subsequent Froude Number (Fr₂) from the following equation:
Fr = \frac{v}{\sqrt{gD}} \quad \ldots [2] 

In which:
g= the acceleration due to gravity (L/T^2).
D= hydraulic depth (L).

3- Based on energy relationships, the general relationship for the flow energy dissipation can be verified, applying energy equations between two sections upstream and downstream weir, we get:

\[ E_1 = Y_1 + \frac{v_1^2}{2g} \quad \ldots [3] \]

\[ E_2 = Y_2 + \frac{v_2^2}{2g} \quad \ldots [4] \]

In which:
E_1= flow energy upstream weir (L).
E_2= flow energy downstream hydraulic jump (L).
v_1,v_2= velocity upstream weir and downstream hydraulic jump respectively (L/T).
Y_1= water depth over weir notch (L).
Y_2= water depth downstream hydraulic jump (L).

3. RESULTS AND DISCUSSION

3.1 Effect of Using Energy Dissipation Blocks on the Relative Energy Dissipation

The results concerning the energy dissipation ratio \((E_2/E_1)\) were plotted against primary Froude Number \((Fr_1)\) for all compound weir notches used in the present study, as shown in figures (4-11). Figure (4) shows the obtained energy dissipation ratio \((E_2/E_1)\) computed at downstream of the hydraulic jump for different types of energy dissipation blocks for compound weirs of half circle lower notch (radius of 10cm). The obtained relative energy dissipation ratio varies between (64.574\%) at maximum discharge of (11.20 \text{ℓ}/g) and (66.418\%) at minimum discharge of (3.0 \text{ℓ}/g) for triangular cutting block with \((\theta=45^\circ)\). The relative energy dissipation ratio \((E_2/E_1)\) increased as \((Fr_1)\) increased roughly for all types of dissipation blocks.

Figure (5) shows that largest average value for \((E_2/E_1)\) was (62.172\%) when using a triangular cut blocks of \((\theta=45^\circ)\) for all discharge values between (3.80 to 11.11 \text{ℓ}/g). Whereas the relative energy dissipation ratio \((E_2/E_1)\) decreased rapidly for increased \((Fr_1)\), almost for all types of energy dissipation blocks, this was due to high turbulence and eddies were clear at the basin bed and the flow surface, especially at high discharges when using horizontal and vertical cut angle blocks were much higher compared to that of triangular cut blocks.
Figure (4): Energy dissipation ratio for compound weir having (R=10cm) lower half-circle notch

Figure (5): Energy dissipation ratio for compound weir having (R=5cm) lower half-circle notch

Figures (6&7) summarizes the obtained values of the relative energy dissipation ratio ($E_2/E_1$) and Froude Number ($Fr_1$) for compound weir having (60°) and (90°) lower V-notches respectively. The relative energy dissipation ratio ($E_2/E_1$) was decreased rapidly with a small difference versus the increase of ($Fr_1$) for the initial discharge rates (i.e., $Fr_1$ values between 0.5 to 1.0) for the weir having lower V-notch (60°), whereas ($E_2/E_1$) values were increased significantly when ($Fr_1$) was increased beyond prescribed range. The minimum average value of ($E_2/E_1$) was (44.519%) which was recorded for a blocks of vertical angle of ($\theta$=60°) as shown in figure (6). For all applied discharge values, the relative energy dissipation ratio ($E_2/E_1$) was decreased as ($Fr_1$) increased (see figure 7), the average value of ($E_2/E_1$) was about (59.167%-55.793%) for all blocks types with a reduction of ($E_2/E_1$) average values of (13.435%-11.274%) for compound weir having(90°) lower V-notch.
Figures (6&7) show the variation of the relative energy dissipation ratio ($E_2/E_1$) and the primary Froude Number with the applied discharges for compound weir having ($30^\circ$) and ($90^\circ$) lower trapezoidal notches respectively. Figure (8) indicates there was a slight decreasing for high discharges. On the other hand, there was no clear change in relative energy dissipation ratio ($E_2/E_1$) between different configurations of blocks especially at the low discharges, i.e., the average value of ($E_2/E_1$) was about (53.943%-51.056%) for all blocks types. Figure (9) shows that flow through compound weir having ($90^\circ$) lower trapezoidal notch, and along dissipation blocks during the experimental runs at the same discharges have the same hydraulic characteristics of the flow that was described for figure(8) above. But with high rate of energy dissipation ratio ($E_2/E_1$) which was about (70.228%) at the maximum discharge of (11.0 lps).
Figures (8&9) show the variation of the relative energy dissipation ratio ($E_2/E_1$) and the primary Froude Number with the applied discharges for compound weir having (2-steps) and (3-steps) lower notches respectively. The obtained values of ($E_2/E_1$) at high discharge with (2-steps) compound weir were less than that of smaller discharges for all blocks configurations. The maximum ($E_2/E_1$) of (68.859%) for a blocks of triangular cut with angle ($\theta=60^\circ$). While, for the rest blocks configurations there were a slight differences at all discharges values with a relative difference of about 1.46 % as shown in figure (10). The relative energy dissipation ratio ($E_2/E_1$) versus Froude Number ($Fr_1$) during the experimental runs at all applied discharges for (3-steps) compound weir was shown in figure (11), the average values of ($E_2/E_1$) were about (62.289%) for a blocks of triangular cut with ($\theta=45^\circ$) to (59.884%) for a block of vertical angle with($\theta=60^\circ$).
3.2 Effect of Using Energy Dissipation Blocks on the Hydraulic Jump and Roller Length

To investigate the effects of using the energy dissipation blocks upon the hydraulic jump location, relative reduction in hydraulic jump length, and length of roller (or recirculation zone) of hydraulic jump for all compound weir notches used in the present study, the results obtained herein were plotted as shown in figures (12-19). Figure (12) shows that minimum average value for relative hydraulic jump length ($L_j / Y_2$) was (5.271) when using a blocks of triangular cut of ($\theta$=45°) for all discharge values between (3.0 to11.2 ℓ/s). The relative hydraulic jump length ($L_j / Y_2$) increases slightly as Froude Number ($Fr_1$) increases for all types and configurations of energy dissipation blocks when using the compound weir having (R=10cm) lower half-circle notch. Figure (13) shows that at maximum applied discharge, the hydraulic jump was formed at shorter distance from the compound weir having (R=5cm) lower half-circle notch with ($L_j / Y_2$) of (5.191) when using blocks of triangular cut with ($\theta$=45°), while for vertical angle cut with ($\theta$=60°) the hydraulic jump was formed...
at longer distance from the weir with $(L_j/Y_2)$ of (16.125). For all types of dissipation blocks the $(L_j/Y_2)$ decreases as $(Fr_1)$ increased within the range of applied discharges.

**Figure (12):** Hydraulic jump length ratio for compound weir having $(R=10cm)$ lower half-circle notch

**Figure (13):** Hydraulic jump length ratio for compound weir having $(R=5cm)$ lower half-circle notch

Figure (14) shows the variation of relative hydraulic jump length $(L_j/Y_2)$ and the Froude Number $(Fr_1)$ with applied discharge for a compound weir having $(60^\circ)$ lower V-notch, $(L_j/Y_2)$ was decreased significantly versus the increase of $(Fr_1)$ for values between (0.4 to 1.0), whereas $(L_j/Y_2)$ values increased when $(Fr_1)$ was increased for higher discharge values. The hydraulic jump was occurred at shorter distance from the compound weir when the value of $(L_j/Y_2)$ was (5.359) which recorded for a blocks of triangular cut with angle of $(\theta=45^\circ)$. For all applied discharge values, the relative hydraulic jump length $(L_j/Y_2)$ were decreased as $(Fr_1)$ increased as shown in figure (15), the shortest and longest distance in which the hydraulic jump formed within stilling basin length were
about (4.794) for a blocks of triangular cut angle with ($\theta=45^\circ$) and (8.917) for a blocks of horizontal cut angle with ($\theta=110^\circ$) respectively.

![Energy Dissipation locks](image1.png)

**Figure (14):** Hydraulic jump length ratio for compound weir having 60° lower V-notch

![Energy Dissipation locks](image2.png)

**Figure (15):** Hydraulic jump length ratio for compound weir having 90° lower V-notch

Figures (16 & 17) show the variation of the relative hydraulic jump length ($L_j/Y_2$) and the Froude Number($F_{r1}$) with the all applied discharge range for compound weir having (30°) and (90°) lower trapezoidal notches respectively. Figure (16) shows there was a rapidly decreasing in ($L_j/Y_2$) as ($F_{r1}$) increase within the limits of lower and moderate flow rates for all blocks types. There were small differences in relative energy dissipation ratio ($L_j/Y_2$) between various configurations of blocks especially at the low discharges; the average value of ($L_j/Y_2$) was about (6.314) for a blocks of triangular cut angle with ($\theta=45^\circ$) to (8.616) for a blocks of horizontal angle with ($\theta=110^\circ$).
Figure (16): Hydraulic jump length ratio for compound weir having (30°) lower trapezoidal notch

Figure (17) shows that flow through compound weir having (90°) lower trapezoidal notch, it’s clear that \( \frac{L_j}{Y_2} \) decreased as \( F_{r1} \) increase within applied discharge range for all blocks types used in the present study, maximum reduction in relative hydraulic jump length \( \frac{L_j}{Y_2} \) of (5.916) occurred when using a blocks of triangular cut with \( (\theta=60^\circ) \), while the minimum reduction of (8.698) for a blocks of vertical cut angles with \( (\theta=60^\circ) \). Generally, there were slight differences on the reduction of relative hydraulic jump length \( \frac{L_j}{Y_2} \) at low discharges for all blocks types and configurations.

Figure (17): Hydraulic jump length ratio for compound weir having (90°) lower trapezoidal notch

Figures (18 & 19) show the variation of the relative hydraulic jump length \( \frac{L_j}{Y_2} \) and the Froude Number \( F_{r1} \) with the all applied discharge range for compound weir having (2-steps) and (3-steps) lower notches respectively. From figure (18) it is clear that relative hydraulic jump length \( \frac{L_j}{Y_2} \) decreases significantly as Froude Number \( F_{r1} \) decreases for all blocks types. At maximum
applied discharge of \((10.5\ell/s)\), the relative hydraulic jump length \((L_j/Y_2)\) was \((12.576)\) for a blocks of vertical cut angle with \((\theta=60^\circ)\), with a free hydraulic jump at a distance \((83.0\text{ cm})\) forward the weir. The shortest average value of \((L_j/Y_2)\) of \((5.374)\) formed when using blocks of triangular cut angle with \((\theta=60^\circ)\).

![Hydraulic jump length ratio for compound weir having (2-steps) lower notch](image1.png)

**Figure (18):** Hydraulic jump length ratio for compound weir having (2-steps) lower notch

Figure (19) makes clear that for a compound weir having (3-steps) lower notch, the \((L_j/Y_2)\) decreased slightly as \((Fr_1)\) increased, and occurred through all applied discharges range. The hydraulic jump occurs at shorter distances measured from the compound weir when using blocks of triangular cut angle with \((\theta=45^\circ)\) in which the average value of \((L_j/Y_2)\) was \((5.933)\).

![Hydraulic jump length ratio for compound weir having (3-steps) lower notch](image2.png)

**Figure (19):** Hydraulic jump length ratio for compound weir having (3-steps) lower notch
Figures (20-22) show the flow through the compound weir models and along the various configurations of energy dissipation blocks, and the hydraulic jump formation during the experimental runs at the applied discharges. High eddies and air entrainment occurred at the bed of channel when the energy dissipaters were used especially at high discharges. Then, more energy will be dissipated. A free hydraulic jump was formed at the downstream of the weir at a different distance according to the flow rate and the configuration. The hydraulic jump occurs at shorter distances measured from the weir front when using energy dissipation blocks in all of the applied discharges. Table (3) summarizes the average values of the primary Froude Number \( \text{Fr}_1 \), and relative jump roller length \( \frac{L}{\Delta Y} \) that were obtained at the applied discharge range.

(a) Arrangement of blocks with horizontal cut angle

Figure (20): Flow along dissipation blocks for compound weir having half circle lower notch

(b) Arrangement of blocks with vertical cut angle

Figure (21): Flow along dissipation blocks for compound weir having stepped lower notch
Figure (22): Flow along dissipation blocks for compound weir having lower V-notch

Table (3): Summary of obtained average values of \( (F_{r1}) \), and roller length \( (Lr/\Delta Y) \) for all blocks and configurations used in this study

<table>
<thead>
<tr>
<th>Type of Dissipation Blocks</th>
<th>Weir Model ( (\theta_w = \text{Weir angle}) )</th>
<th>Discharge Range ( (A) )</th>
<th>( (F_{r1}) ) ( (B) )</th>
<th>( (Lr/\Delta Y) ) ( (A) )</th>
<th>( (Lr/\Delta Y) ) ( (B) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks of triangular cut angle:</td>
<td>Rectangle with lower half circle notch ( R=5,10\text{cm} )</td>
<td>3.1-11.9</td>
<td>0.80</td>
<td>0.78</td>
<td>5.26</td>
</tr>
<tr>
<td>Configuration(A): ( \theta=45^\circ )</td>
<td></td>
<td>3.1-11.9</td>
<td>1.17</td>
<td>1.08</td>
<td>8.60</td>
</tr>
<tr>
<td>Configuration(B): ( \theta=60^\circ )</td>
<td>Rectangle with lower V-notch ( \theta=60^\circ,90^\circ )</td>
<td>3.1-11.1</td>
<td>0.82</td>
<td>0.84</td>
<td>2.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.3-11.1</td>
<td>0.46</td>
<td>0.50</td>
<td>3.21</td>
</tr>
<tr>
<td>Rectangle with lower trapezoidal notch ( \theta=30^\circ,90^\circ )</td>
<td>3.1-11.1</td>
<td>0.67</td>
<td>0.74</td>
<td>2.78</td>
<td>3.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2-11.6</td>
<td>0.67</td>
<td>0.74</td>
<td>5.95</td>
</tr>
<tr>
<td>Rectangle with stepped lower notch ( 2,3 ) steps</td>
<td>3.3-10.5</td>
<td>0.79</td>
<td>0.83</td>
<td>7.24</td>
<td>10.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.9-11.6</td>
<td>0.85</td>
<td>0.87</td>
<td>5.18</td>
</tr>
<tr>
<td></td>
<td>Rectangle with lower half circle notch ( R=5,10\text{cm} )</td>
<td>3.1-11.9</td>
<td>1.32</td>
<td>1.14</td>
<td>8.63</td>
</tr>
<tr>
<td>Blocks of horizontal cut angle:</td>
<td></td>
<td>3.1-11.9</td>
<td>1.13</td>
<td>1.08</td>
<td>8.63</td>
</tr>
<tr>
<td>Configuration(A): ( \theta=60^\circ )</td>
<td>Rectangle with lower half circle notch ( \theta=60^\circ,90^\circ )</td>
<td>3.1-11.1</td>
<td>1.07</td>
<td>1.15</td>
<td>2.22</td>
</tr>
<tr>
<td>Configuration(B): ( \theta=110^\circ )</td>
<td></td>
<td>3.3-11.1</td>
<td>0.50</td>
<td>0.49</td>
<td>3.40</td>
</tr>
<tr>
<td>Rectangle with lower trapezoidal notch ( \theta=30^\circ,90^\circ )</td>
<td>3.1-11.1</td>
<td>0.66</td>
<td>0.68</td>
<td>3.40</td>
<td>3.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2-11.6</td>
<td>0.75</td>
<td>0.67</td>
<td>7.50</td>
</tr>
<tr>
<td>Rectangle with stepped lower notch ( 2,3 ) steps</td>
<td>3.3-10.5</td>
<td>0.82</td>
<td>0.87</td>
<td>7.31</td>
<td>9.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.9-11.6</td>
<td>0.94</td>
<td>0.93</td>
<td>5.78</td>
</tr>
<tr>
<td></td>
<td>Rectangle with lower half circle notch ( R=5,10\text{cm} )</td>
<td>3.1-11.9</td>
<td>1.42</td>
<td>1.16</td>
<td>11.62</td>
</tr>
<tr>
<td>Blocks of vertical cut angle:</td>
<td></td>
<td>3.1-11.9</td>
<td>1.24</td>
<td>1.09</td>
<td>13.02</td>
</tr>
<tr>
<td>Configuration(A): ( \theta=60^\circ )</td>
<td>Rectangle with lower V-notch ( \theta=60^\circ,90^\circ )</td>
<td>3.1-11.1</td>
<td>0.86</td>
<td>0.92</td>
<td>2.58</td>
</tr>
<tr>
<td>Configuration(B): ( \theta=110^\circ )</td>
<td></td>
<td>3.3-11.1</td>
<td>0.46</td>
<td>0.44</td>
<td>4.03</td>
</tr>
<tr>
<td>Rectangle with lower trapezoidal notch ( \theta=30^\circ,90^\circ )</td>
<td>3.1-11.1</td>
<td>0.69</td>
<td>0.78</td>
<td>3.38</td>
<td>3.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2-11.6</td>
<td>0.58</td>
<td>0.71</td>
<td>6.18</td>
</tr>
<tr>
<td>Rectangle with stepped lower notch ( 2,3 ) steps</td>
<td>3.3-10.5</td>
<td>0.82</td>
<td>0.84</td>
<td>8.26</td>
<td>8.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.9-11.6</td>
<td>0.94</td>
<td>0.93</td>
<td>6.27</td>
</tr>
</tbody>
</table>
4. CONCLUSIONS

Based on the results obtained in this study, the following conclusions were achieved:

1- Arrangement containing the use of compound weir with (60°) lower V-notch and dissipation blocks of horizontal cutting angle configurations (60°, 110°) were produced maximum reduction in flow energy of (54.7% to 55.4%) respectively for all the applied range of discharge.

2- Configuration included use of compound weir with (60°) lower V-notch and dissipation blocks of triangular cutting angle configurations (45°, 60°) have the smallest value of the relative hydraulic jump length ($L_j/Y_2$) of (5.36 to 6.02) respectively for all the applied range of discharge compared with configurations in this study.

3- The relative jump roller length (recirculation zone), with above configuration was about (1.94) at minimum applied discharge of (3.2ℓ/s), and was about (2.14) at maximum applied discharge of (10.3ℓ/s) for blocks of triangular cut angle with (θ=60°).

4- The obtained results indicate that use the configuration containing compound weir with (60°, 90°) lower V-notch with all dissipation blocks have a high efficiency especially at the high discharges.

5. REFERENCES